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Impact of soil health management practices on soilborne pathogens, nematodes and root diseases of vegetable crops

G.S. Abawi*, T.L. Widmer

Department of Plant Pathology, NYSAES, Cornell University, Geneva, NY 14456, USA

Abstract

Various cultural practices, including the use of cover and rotational crops, composts, tillage systems, and others have been promoted as management options for enhancing soil quality and health. All cultural practices are known to directly or indirectly affect populations of soilborne pathogens and the severity of their resultant root diseases. Soil biology is a major component and contributes significantly to soil quality and productivity. The major activities of soil microbes include the decomposition of organic materials, mineralization of nutrients, nitrogen fixation, suppression of crop pests and protection of roots, but also parasitism and injury to plants. Thus, there is a great need to assure that the introduced soil management practices to improve soil quality will also result and maintain a healthy soil. The latter include the abundance and diversity of total soil microbes, high population of beneficial organisms and low population and/or activities of crop pests. Production of vegetables and other food crops is often significantly affected by several soilborne pathogens that require control. The incidence and severity of root diseases is an indirect assessment of soil health for specific commodity/soil use. In addition, understanding and selecting the appropriate cultural practices that limit or prevent damage of root diseases is essential for the long-term and sustainable management of soil quality and health. Case-study examples are presented to illustrate the impact of cover crops and their green manures on the density and damage of root-knot and lesion nematodes to vegetables; and also tillage, soil amendments, crop rotation, and cover crops on bean yield and root rot severity. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Soil quality; Plant-parasitic nematodes; Pathogenic fungi; Soil biology; Cultural practices

1. Introduction

Soil is part of the dynamic, living, natural terrestrial ecosystem. In practical terms, soil consists of four major components: mineral materials, organic matter, water, and air (Buckman and Brady, 1960). An important component, which is often overlooked, is the biological aspect. Essential parts of the global carbon, nitrogen, phosphorous, sulfur, and water cycles are carried out in soil largely through microbial and faunal interactions with soil physical and chemical properties (Doran and Parkin, 1996). In recent years, there has been an increased recognition that the soil is essentially a 'nonrenewable resource.' It has become clear that the economics of agricultural production depends heavily on how well the soil productivity is maintained. This awareness has focused attention on soil management programs that promote sustainable soil quality, productivity and health (Magdoff, 1992; Doran and Jones, 1996; Pankhurst et al., 1997). A number of alternative tillage practices, cover and rotational crop schemes, use of various composts and mulches, planting systems and others are being promoted for many production systems. The elucidation of the effect of such alternative practices on soilborne pathogens is needed for the design of soil and crop management systems

* Corresponding author.

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that are also suppressive to soilborne pathogens and their root diseases. Several books and review articles have been written on this subject and ways to assess and quantify it (Doran et al., 1994; Doran and Jones, 1996; Lewis et al., 1997; Pankhurst et al., 1997).

Organic matter is one of the most important components of soil (Magdoff, 1992). Many of the soil's biological, physical, and chemical properties are a function of soil organic matter. Organic matter has many benefits including increasing plant nutrient availability, providing a favorable physical condition for plant growth, increasing soil buffering capacity, stimulating root development, increasing biological diversity, and facilitating a number of global cycles such as carbon and nitrogen. In today's farming practices, the lack of replenishing the organic matter in the soil after harvest is a very important problem. As soil organic matter decreases, it becomes more difficult to grow plants because problems of fertility, water availability, compaction, erosion, disease, and insects become more common. This requires higher levels of fertilizers, irrigation water, and pesticides to maintain yields.

Vegetables are grown on almost 1.5 million hectares in the US with a total value of over US$ 9 billion (USDA, 1998). In New York alone, vegetables are grown on over 67,000 ha worth over US$ 203 million. Consumers and wholesale buyers demand high quality vegetables, including proper size, perfect shape, and no blemishes. Unfortunately, there are many factors including several soilborne pests and diseases of vegetables that are known to negatively and substantially affect both the yield and quality of vegetables. Root diseases incited by fungal and nematodal soilborne pathogens are of common occurrence on many vegetables, including beans, onions, lettuce, and carrots, grown in New York, the northeast (NE) region of the USA, and elsewhere (Abawi et al., 1985; Sherf and MacNab, 1986; Hall, 1991). Root diseases are most severe and cause considerable losses to vegetables when soil conditions are poor such as high compaction with inadequate drainage or low organic matter content. In addition, root diseases are also prevalent when susceptible crops are used in a sequence that permits the build-up of high population densities of soilborne plant pathogens.

All economically important plants are damaged by one or several diseases that can greatly limit the yield potential and the quality of the harvested produce (Agrios, 1988). The primary methods to manage fungal diseases are crop rotation, host resistance, and especially the use of chemical fungicides. A fungicide usually contains one or more active ingredients that affects the pathogen. Fungicides are a necessity to the farmer to grow crops economically, increase harvest yields and quality, and protect from losses in the field and during storage. In 1994, the global fungicide market was estimated at US$ 5.4 billion (Hamlen et al., 1997). Fungicides applied to protect fruits and vegetables represent 46% of the world market value. Recently, fungicide use has steadied due to the development of new highly active molecules used at lower rates, the increased promotion and adoption of integrated pest management (IPM) methods, and other methods.

Currently, the primary control measures employed against plant-parasitic nematodes are chemical nematicides and crop rotation as well as the use of resistant cultivars, when available. However, there has been a strong reliance on the use of agricultural chemicals for total pest control throughout the world. The latter was reflected in recent statistics, indicating that farmers spend about US$ 20 billion worldwide, and US$ 6–8 billion annually in the US on crop protection (Biotechnology Processing, March 1991). About 3% of this figure, US$ 172 million in the US are spent for nematicides. The use of nematicides, especially the broadspectrum fumigants, has been very effective in controlling nematodes and their damage to crop plants in the NE region of the US and worldwide. At times, crop yields in fumigated plots have been increased several fold over the yield of nontreated plots and beyond what is expected of nematode control.

However, nematicides are highly toxic and have been recognized as contributing risks to human health and damaging the environment. In addition, nematicides must generally persist in soil for some time in order to effectively control plant-parasitic nematodes. Unfortunately, many of these nematicides have been proven to be carcinogenic, to build up in residues in food crops, and to infiltrate into ground water. These undesirable features have led to a total ban or restriction on the use of most nematicides, especially fumigant-type chemicals by the Environmental Protection Agency, while uses of most other nematicides are currently under review. For example, the nematicides 1,3-D, Aldicarb, Vorlex, and all granular formulations of carbofuran have been banned or are under review in various regions of the entire country. In addition, methyl bromide, widely used for control of nematodes, weeds, and soilborne pathogens, has been scheduled to be totally banned by the year 2005 in the US, as it has been detected at undesirable levels as an air pollutant and implicated in ozone depletion in the atmosphere. Only two potentially new nematicides, phosthiazate (ISK, Japan) and dazonet (BASF) are being field-tested. The current trend indicates that chemical nematicides may not be available in the near future for use in the industrialized nations. It appears that the use of agricultural chemicals in developing nations must also be reduced due to both local concerns and enacted legislation in the industrialized nations regulating the levels of pesticides in imported foodstuffs. Thus, the development of alternative control strategies and tactics to replace or complement chemical nematicides for the management of plant-parasitic nematodes is urgently needed (Barker and Koenning, 1998).

Almost all crop production practices have a direct and/or indirect impact on root disease incidence and severity. Of particular influence are cover crops, mulches and composts, tillage systems, cropping sequences, planting systems, and others (Cook et al., 1978; Sumner et al., 1981; Cook and Baker, 1983; Allmaras et al., 1988; Abawi and Thurston, 1992). These practices not only influence population densities of major and minor soilborne pathogens, but also total crop pests and beneficial soil microflora and fauna. Thus, there is a great need to expand our knowledge of the effects of current and alternative production practices on soilborne pathogens and the severity and damage of their root diseases.

The purpose of this article is to give selected case studies on how known cultural practices improve soil quality and health and impact root diseases. It is important to diagnose accurately the pathogen(s) involved in the specific production system. There is some conflict of data on the impact of cultural practices reported in the literature on specific pathogens, most likely a result of different growing conditions and systems. For example, *Rhizoctonia solani* has been shown to increase under reduced tillage systems (Sumner et al., 1986a,b; Abawi and Crosier, 1992) while use of surface mulch in the humid tropics decreased severity of disease caused by this pathogen (Galindo et al., 1983). Another example in the importance of knowing the pathogen(s) involved is in the selection of a cover crop. Hairy vetch has been shown to be very effective in suppressing *Thielaviopsis basicola* (Rothrock et al., 1995). However, hairy vetch increases damage caused by the lesion nematode, *Pratylenchus penetrans*, not only because it does not have any suppressive activity towards this nematode, but hairy vetch is also an efficient host (Abawi and Ludwig, 1995). Thus, it is critical to evaluate these cultural practices under different production systems infested with their specific pathogen and nonpathogen communities before definite and general conclusions can be made.

2. Cover crops incorporated as green manures

Cover crops are typically grown during the off-season with an annual cash crop. Cover crops have usually been turned under prior to planting the cash crop. When they are incorporated into the soil they become a ‘green manure.’ Cover crops may or may not have any harvestable yield value. However, they have been demonstrated to reduce erosion (Wall et al., 1991; Creamer et al., 1997), improve the physical characteristics of the soil (Reid and Goss, 1981), and reduce plant diseases (Sumner et al., 1981). Green manures have also been shown to increase soil organic matter (Allison, 1973), increase microbial activity (Cook and Baker, 1983; Harris et al., 1994), and suppress plant diseases (Baker and Cook, 1974; Abawi and Crosier, 1992; Viaene and Abawi, 1998).

Root rot is a major disease complex of beans grown in New York, causing substantial economic losses annually (Abawi et al., 1985). This diseases complex is caused by several pathogenic fungi (*Fusarium solani* f. sp. *phaseoli*, *R. solani*, *Pythium ultimum*, and *T. basicola*) and the plant-parasitic nematode (*Pratylenchus* spp.) individually or in any possible combination. For example, results of a greenhouse test have shown that green manures of the cover crops included differed significantly in their suppression of root rot severity and damage to bean growth (Figs. 1 and 2). In addition, differential effects of green manures of various cover crops on the severity of root rot and bean yield have also been observed under field conditions. For example, a recent test demonstrated that a previous cover crop of grain rye incorporated

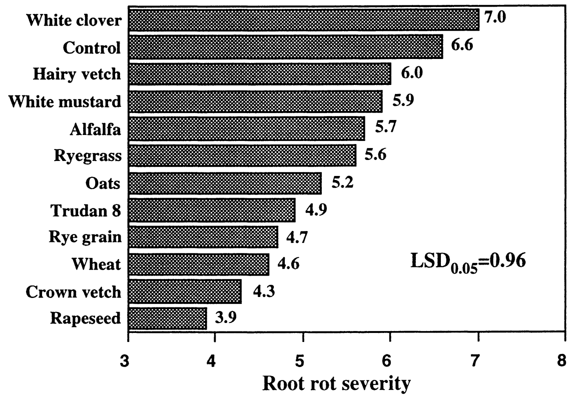

Fig. 1. The effects of various incorporated cover crops on root rot severity of snap bean (*P. vulgaris* L.) in a greenhouse test. Roots were rated on a scale of 1 (no root rot observed) to 9 (>80% of the roots infected). Numbers after the bar graph represent the actual values. Statistical differences compared by Fishers least significant difference test ($LSD_{0.05}$).

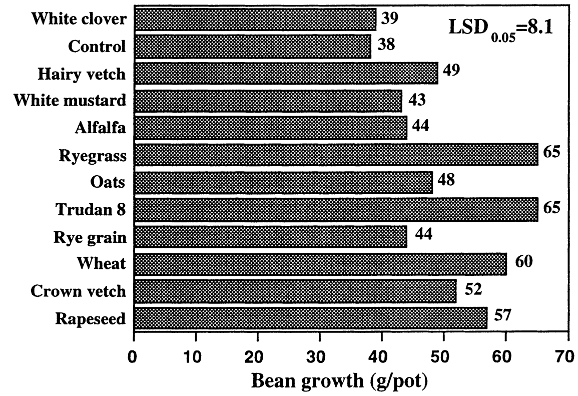

Fig. 2. Impact of various green manures on the growth of snap bean (*P. vulgaris* L.) after 8 weeks in a greenhouse test. Numbers after the bar graph represent the actual values. Statistical differences compared by Fishers least significant difference test ($LSD_{0.05}$).

as a green manure resulted in the highest bean yield and slightly lower root rot severity ratings, whereas that of hairy vetch resulted in the lowest yield and the highest root rot severity ratings (Fig. 3).

A number of cover crops and green manures can be effective in suppressing nematode populations and infections (Mojtahedi et al., 1991; Mojtahedi et al., 1993; Halbrendt, 1996). Viaene and Abawi (1998) found that sudangrass was effective, as a green manure, in reducing reproduction of *Meloidogyne hapla* and, therefore, its damage to lettuce plants. The first step in determining an effective cover crop/green manure is to examine its host suitability to the target nematode. Ideally, the cover crop would be grown in the same field as the main crop between harvesting and planting. So, it is important that the cover crop is a poor host or nonhost to the nematode. Oat, rye, and sudangrass were all shown to be nonhosts or poor hosts to *M. hapla* (Faulkner and McElroy, 1964; Mojtahedi et al., 1993; Viaene and Abawi, 1998) and phacelia, yellow mustard and oilseed radish are maintenance

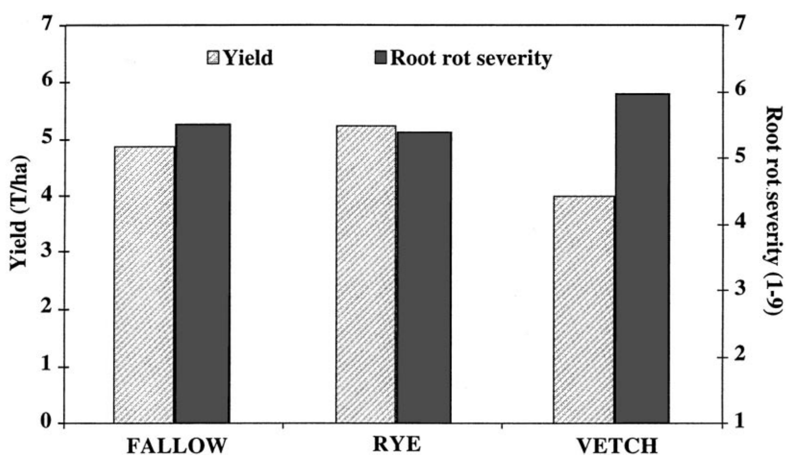

Fig. 3. The effect of a rye or vetch cover crop in comparison to fallow in a continuous bean rotation on yield (t/ha) and root rot severity (scale of 1 — no root rot to 9 — >80% roots infected). Means were compared by Fishers least significant difference (yield: $LSD_{0.05}$=0.7; root rot severity: $LSD_{0.05}$=0.3).

hosts (Viaene and Abawi, 1998). However, when incorporated into the soil, most of the cover crops did not affect nematode populations.

Of the cover crops tested, sudangrass cv. Trudan 8 (*Sorghum sudanense* × *S. sudanense*) showed the most promise in reducing egg production and root gall severity of *M. hapla*. However, there is some variability in the influence of sudangrass on growth of lettuce in the greenhouse (Viaene, 1996). This growth reduction demonstrates that phytotoxicity can occur to the host plant if the green manure is not allowed enough time to decompose properly or completely. In greenhouse tests, we have generally planted lettuce 4 weeks after the incorporation of sudangrass tissues. The age and plant part of the sudangrass incorporated into the soil is important in its effectiveness in suppressing *M. hapla* and its damage (Viaene and Abawi, 1998). Tissue of 1- or 2-month-old was more effective than 3-month-old tissue of sudangrass. Furthermore, soil amended with all parts of sudangrass resulted in lower reproduction of *M. hapla* on lettuce than soil amended with only roots of sudangrass. The latter illustrates the importance of proper management of cover crops for best benefit in suppressing nematodes and improving yields.

In field microplots, the effective nature of suppression of sudangrass against *M. hapla* was observed even when the initial nematode populations were high. Lettuce and carrot yields in organic soil amended with sudangrass at initial population densities of eight eggs of *M. hapla*/cm^3 soil were higher than the nonamended plots (Viaene and Abawi, 1998; Widmer and Abawi, 1998a). In field microplots filled with organic soil infested with *M. hapla*, incorporation of sudangrass grown as a cover crop from late summer to fall resulted in 20–30% increase in the weight of lettuce planted the following spring as compared to lettuce planted in nematode-infested soil that was left fallow. When sudangrass was incorporated the previous fall (10 t/ha) in field microplots filled with organic soil and initially infested with eight eggs of *M. hapla*/cm^3 soil, the marketable yield of carrots was increased by 18%.

In general, there are three possible mechanisms which may play a part in nematode suppression by green manures: biological, chemical, or a combination of these two. As mentioned previously, a wide range of organisms inhabit the soil environment. Many of these organisms are dependent upon each other in a complex food web. In previous studies (Rothwell and Hortenstine, 1969; Gallardo-Lara and Nogales, 1987), incorporation of organic matter has been shown to increase microbial activity. Biologically, there are different ways that beneficial microorganisms act upon pathogenic organisms. Populations of soil-inhabiting organisms can affect plant pathogenic organisms by competition (nutrients, space, water, etc.) and direct predation or parasitism (Baker and Cook, 1974).

Chemical mechanisms, by the production of volatile and nonvolatile toxic compounds during decomposition, have been demonstrated to inhibit plant-parasitic nematodes (Patrick et al., 1965; Abawi and Thurston, 1994). For example, sudangrass contains a compound in the cell cytoplasm called dhurrin, a cyanoglucoside. When the plant cell is broken down, such as occurs during decomposition, an enzyme degrades the dhurrin further to a final product that releases hydrogen cyanide (Adewusi, 1990). Other products of this degradation, such as nitriles or isothiocyanates, may also have nematicidal properties (Donkin et al., 1995). Our preliminary data suggest that exposing eggs of *M. hapla* to a water extract of sudangrass tissues result in a reduction of *M. hapla* infection in lettuce roots (Widmer and Abawi, 1998b).

The other important nematode to commercial crops in the state of New York is the lesion nematode, *Pratylenchus* spp. This nematode reduces or inhibits root development by forming local lesions on young roots and destroying cortical root tissues through movement, feeding, and depositing eggs. Infected roots are predisposed to infection by secondary fungi or bacteria and eventually rot. These infections can result in a reduced plant stand and lower yields. Crop rotation is not very successful because of the wide host range of this nematode. Good control can be achieved with chemical nematicides; by summer fallow and aerating the soil, which reduces the nematode population by exposing the nematodes to heat and drying; and by eliminating host plants. However, leaving a field fallow can lead to erosion, reduced profitability, and other problems. Thus, there is interest in appropriate cover crops and green manures as a viable alternative in the management of lesion nematodes.

Reproduction of *P. penetrans* on selected cultivars of hairy vetch, crown vetch, red clover, white clover, alsike clover, alfalfa, ryegrass, rye grain, oat, sudangrass hybrid, buckwheat, mustard, oilseed radish, and

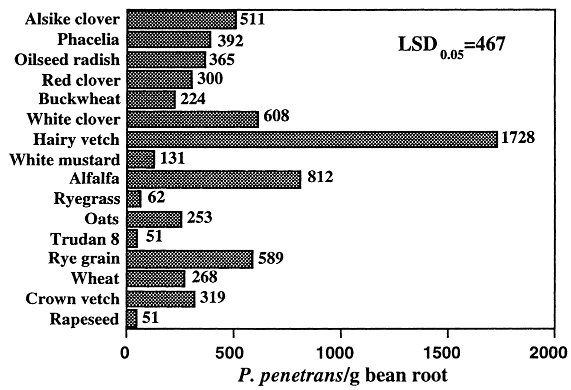

Fig. 4. The influence of various cover crops incorporated into the soil on the population of *P. penetrans* extracted after planting bean for 8 weeks in a greenhouse test. Numbers after the bar graph represent the actual values. Statistical differences compared by Fishers least significant difference test ($LSD_{0.05}$).

rape were evaluated in the greenhouse (Abawi and Ludwig, 1995). Eight weeks after inoculation with a known population of *P. penetrans* (P_i), the final population (P_f) was extracted from roots and soil and the reproductive factor was calculated ($R=P_f/P_i$) for each crop. Only ryegrass was a poor host ($R<1$) to *P. penetrans*. Hairy vetch was the most efficient host ($R>5$). Most of the other crops were considered as intermediate hosts.

In another test, the same cover crops were incorporated into the soil, infested with *P. penetrans*, and planted with bean (*Phaseolus vulgaris*) to test for any suppressive behavior of the crops as green manures. The most efficient green manures were those of sudangrass, rapeseed, and ryegrass (Fig. 4). The number of *P. penetrans* per gram of bean root increased dramatically when alfalfa and hairy vetch were grown for 8 weeks and then incorporated as a green manure into the soil 4 weeks prior to planting beans.

These results demonstrate that the use of cover crops/green manures can be highly effective in managing root-knot and lesion nematodes as well as root rot pathogens. However, the soil environment is very complex and different geographical areas have different soil environments. First, it is important to select potential cover crops/green manures that are adapted and can best fit into the normal crop rotation. Secondly, the various selected cover crops must be tested for their host suitability to the target pathogen(s) and to assess how effective they would be to suppress plant pathogens when incorporated into the soil. It is best to conduct preliminary tests in the greenhouse or small experimental plots before attempting larger scale field trials. However, pathogen suppression in the greenhouse or experimental field plots does not guarantee similar levels of suppression in production fields under diverse soil and environmental conditions and also diverse management options.

3. Composts

Composting is becoming an effective way to manage and recycle municipal and industrial waste. It converts organic wastes into a stabilized form, reduces the volume of waste material, destroys human pathogens, provides a means of recycling valuable plant nutrients, and can be used as an effective and desirable soil organic amendment (Hoitink and Fahy, 1986; Dick and McCoy, 1993). In addition to increasing organic matter of the soil, amending with composts also increases soil microbial populations (Pera et al., 1983; Perucci, 1990), which leads to an improvement of the soil quality. The suppressive activity of compost towards plant pathogens has been well documented with the majority of success shown in containerized systems (Hoitink and Fahy, 1986; Nelson and Craft, 1992). However, our understanding of how the addition of compost interacts in agricultural soils is limited and there is some inconsistency in the reports, probably due to the different experimental conditions.

Chen et al. (2000) found that the application of brewery compost reduced root galling severity and egg production of *M. hapla* and increased yield of lettuce by 13% in fumigated soil and 23% in nonfumigated soil. The effects of brewery compost and corn silage soil amendment with and without a cover crop mixture of rye grain/hairy vetch was evaluated against the bean root rot complex in a replicated field test over three growing cycles. The annual rates of the brewery compost, corn silage, and the green manures of the cover crop mixture averaged 27, 34, and 56 t/ha, respectively. The use of a mixture of a rye/vetch as a cover crop significantly increased plant population, increased pod yield and slightly reduced root rot severity ratings (Fig. 5). In the fallow plots, the addition of the brewery compost resulted in significant increases

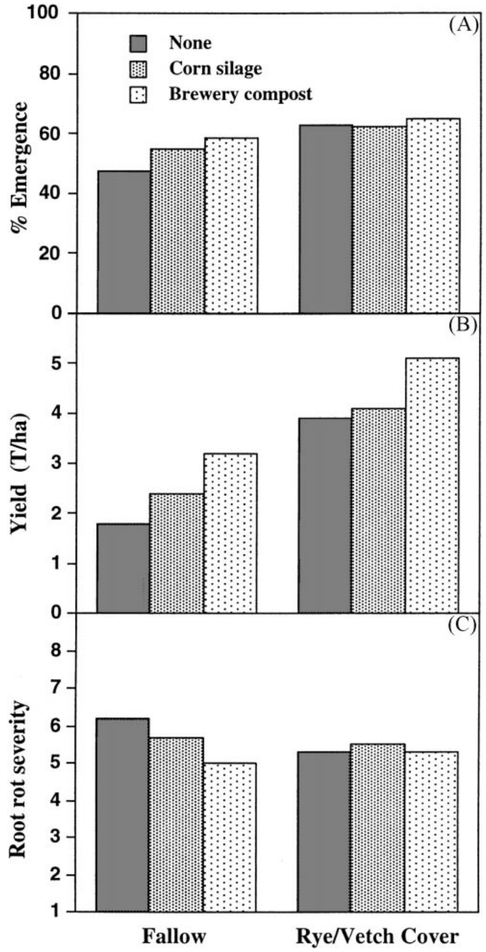

Fig. 5. Data from a trial conducted in the field showing the effects of brewery compost or fresh corn silage amendment with and without a rye/vetch cover crop on the (A) emergence of snap beans (fallow $LSD_{0.05}$=7.7; cover crop $LSD_{0.05}$=6.9), (B) bean yield (fallow $LSD_{0.05}$=1.4; cover crop $LSD_{0.05}$=2.1), and (C) root rot severity rating (fallow $LSD_{0.05}$=0.6; cover crop $LSD_{0.05}$=0.7).

in plant population and pod yield as well as a significant reduction in root rot severity ratings. The addition of the fresh corn silage also exhibited similar effect as the brewery compost, but the differences were not statistically significant. Interestingly, the addition of the brewery compost and the corn silage did not show clear beneficial effects in combination with the rye/vetch mixture as a cover crop, although plant population and pod yield were higher in the plots receiving the two amendments. In another 4-year test, the annual application of chicken compost (11 t/ha) resulted in a significant reduction of the number of lesion nematode extracted from bean roots and also significantly increased total biomass of snap bean, but not pod yield (Table 1).

Table 1
The effect from one field test, after the application of poultry compost, on the number of *P. penetrans* per gram of bean root, the total biomass of bean and the pod weight

Factor	Compost[a]	No compost
No. *P. penetrans*/g root	18	41
Total plant biomass (t/ha)	22.5*	20.3
Pod weight (t/ha)	5.7	5.4

[a] Poultry compost applied at a rate of 11 t/ha prior and incorporated into the soil prior to planting.
* Significantly different, $P<0.05$.

4. Crop rotation

Practicing an appropriate crop rotation is an effective and practical management option against root rot pathogens of many crops, including beans. Rotation of beans with grain crops such as corn, wheat, barley, rye, or oat has been reported to decrease severity and damage of several fungal and nematodal root rot pathogens (Snyder et al., 1959; Patrick et al., 1964; Glynne, 1965; Cook and Baker, 1983; Trivedi and Barker, 1986; Abawi, 1989). Although a number of the crop rotations have been shown to reduce soil populations of bean pathogens, many of the beneficial effects of crop rotations have also been attributed to their direct and indirect effects on the physical and chemical properties of soil as well as to promoting the activities of beneficial microorganisms. Over the years, several researchers have evaluated the effect of crop rotations on bean root rot in New York. For example, Maloy and Burkholder (1959) reported that growing beans after wheat resulted in reduced root rot severity and increased yield. They also concluded that a minimum of 3-year rotation with wheat was needed in fields with a history of severe root rot incidence, whereas rotation had little effect in fields with low to moderate root rot severity. Natti (1965) reported that lowest root rot severity and highest yield of Kidney beans were obtained in plots that were planted to oats in the previous three seasons. He also concluded that planting bean following cabbage resulted in about 50% reduc-

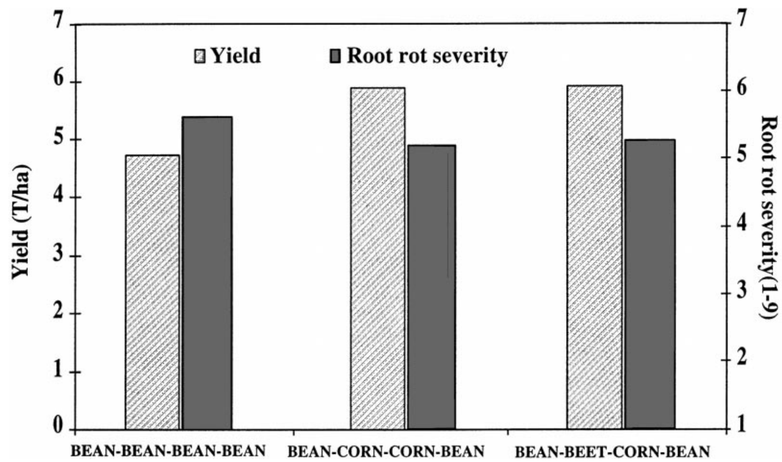

Fig. 6. Results of a test conducted in the field showing the effect of various crop rotations on yield (t/ha) ($LSD_{0.05}$=0.2) and root rot severity of snap bean (scale of 1 — no root rot to 9 — >80% roots infected) ($LSD_{0.05}$=0.4).

tion in bean yield and considerable increase in root rot severity. He also showed that the lowest bean yield and most severe root rot incidence occurred in bean plots that were in fallow for 3 years. Furthermore, he observed that eight successive plantings of beans resulted in an overall reduction of root rot severity, which became apparent only after 4 years. In a more recent study, a 2-year rotation out of beans (2 consecutive years of sweet corn or 1 year of table beet and 1 year of sweet corn) significantly increased bean yield (pod yield by 25%) and slightly reduced root rot severity ratings, as compared to a monoculture of bean production (Fig. 6). A 2-year rotation with nonhosts to the sugar beet-cyst nematode (*Heterodera schachtii*) such as corn or wheat was found necessary to reduce the population and damage of this nematode to table beets and cabbage in New York (Mai and Abawi, 1980).

5. Tillage practices

Tillage practices that reduce soil compaction, increase drainage, and increase soil temperature have been shown to generally reduce the severity and damage of root rot pathogens to many vegetables, including beans. Loosening the soil by breaking hard pans and subsoiling after seedbed preparation were found to reduce *Fusarium* root rot damage and increase yield of beans (Burke, 1965; Burke et al., 1972). The beneficial effect of loosening the soil on bean yield was attributed mainly to the greater penetration and greater formation of roots, especially at deeper soil depths where the densities of root rot pathogens is rather low. Deep plowing and turning under of infected crop residue have been shown to reduce a number of bean diseases such as *Rhizoctonia* root rot (Sumner and Boosalis, 1981; Lewis et al., 1983; Sumner et al., 1986a,b) and to increase colonization of bean roots by beneficial mycorrhizal fungi (Mulligan et al., 1985). Also, exposure of bean roots to excessive wetting periods has been shown to increase their susceptibility to damage by *Fusarium* root rot and other pathogens (Miller and Burke, 1975; Miller and Burke, 1977). In addition, high soil moisture is known to increase the development and damage of *Pythium* root rot, *Rhizoctonia* root rot and other pathogens (Pieczarka and Abawi, 1978a,b,c). Recent results have demonstrated that subsoiling of root rot fields the previous fall resulted in significant increase in plant population and yield of beans (Fig. 7). However, the average root rot severity ratings were not affected by subsoiling. In addition, the benefit of subsoiling was evident for only 1 year, when conventional land preparation practices with heavy equipment were utilized. Bean roots were larger and deeper in the plots that had been subsoiled the previous fall. Thus, it was concluded that subsoiling broke up compacted plow layers, resulting in bigger and deeper root systems that are more efficient

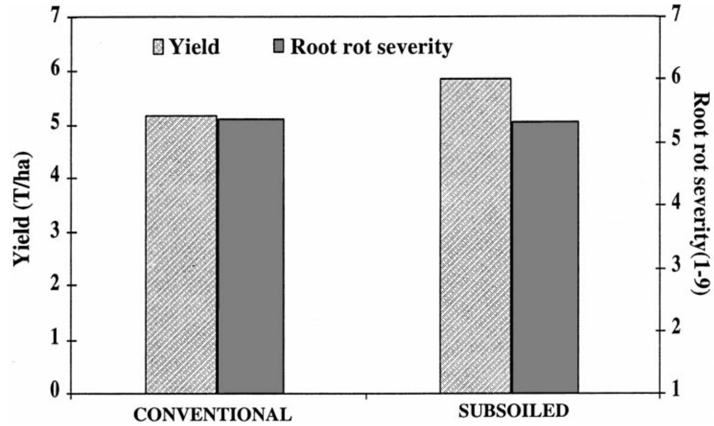

Fig. 7. Data from a test conducted in the field showing the effect of tillage on yield (t/ha) ($LSD_{0.05}$=0.5) and root rot severity of snap bean (scale of 1 — no root rot to 9 — >80% roots infected) ($LSD_{0.05}$=0.3).

and tolerant of damage by root pathogens. Results from another reduced tillage experiment showed that beans grown in the rototilled and chisel-plowed plots had significantly higher root rot severity than those grown on the normally-plowed (moldboard) plots established in a heavily infested field with root rot pathogens (Abawi and Crosier, 1992). Also, total and pod weights of beans were highest in the normally plowed plots and were significantly reduced by the other tillage practices. Symptoms of *Rhizoctonia*, *Fusarium*, and *Thielaviopsis* root rots, in descending order, were evident on the plants in the test field. It was concluded that reduced tillage practices, especially rototilling only the planting rows, would increase root rot severity in heavily infested fields, resulting in poor growth and lower yield. Control measures for root rot pathogens, especially *R. solani* that is associated with crop residue, need to be applied if such practices are employed.

Similarly, the effects of raised ridges on root rot severity and yield of snap beans was evaluated in experimental and commercial bean fields in New York from 1978 to 1986. Beans grown on raised ridges generally yielded higher and exhibited lower root rot severity as compared to those grown on flat seedbeds, especially during cool and rainy periods (Abawi, 1991). Soil around bean roots grown on raised ridges were always drier and warmer as compared to that on flat seedbeds. In addition, roots of bean plants grown on ridges were found to grow deeper and wider than those grown on flat seedbeds.

6. Conclusions

Soilborne diseases are most damaging when soil conditions are poor as a result of inadequate drainage, poor soil structure, low organic matter, low soil fertility, and high soil compaction. The aforementioned cultural practices all have an impact on these physical characteristics as well as increasing the diversity of the soil biota. Implementation of these practices improves the soil health and reduces disease incidence in a sustainable manner.

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